Contributions to Entomology 76 (1) 2026, 75–82 | DOI 10.3897/contrib.entomol.76.e186606

CONTRIBUTIONS TO ENTOMOLOGY

SENCKENBERG NATURE RESEARCH

Research Article

Thermal-dependent development and life table attributes of *Orius albidipennis* (Reuter, 1884) (Hemiptera: Anthocoridae) at different constant temperatures

Ahmed H. El Kenawy[1], Dina A. H. Atwa[1], Doaa S. AbdelMotaal[1], Mohammad Ali Abdelhady[2]

1 *Biological Control Research Department – Plant Protection Research Institute – Agricultural Research Centre, Giza, Egypt*

2 *Plant Protection Department, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt*

https://zoobank.org/2F060F4B-4E20-4E7B-958E-EE011533E1A8

Corresponding author: Ahmed H. El Kenawy (ahmed.elkenawy@libero.it)

Academic editor: Thomas Schmitt | Received 27 January 2026 | Accepted 3 April 2026 | Published 28 April 2026

Abstract

This study investigates the temperature-dependent development and life table parameters of the predatory bug *Orius albidipennis* (Reuter, 1884) (Hemiptera: Anthocoridae) under three constant temperatures (20, 25, and 30°C). Using age–stage, two-sex life table analysis with 15 replicates per temperature, we assessed stage-specific developmental rates, longevity, fecundity, fertility, and population growth metrics. Developmental time decreased significantly with increasing temperature, with total nymphal duration ranging from 18.05 days at 20°C to 9.62 days at 30°C. Optimal reproductive performance occurred at 25°C, where net reproductive rate (R_0 = 49.4 female offspring/female), intrinsic rate of increase (r = 0.131 day^{-1}), and egg hatch (86.4%) peaked. Higher temperatures (30°C) reduced fertility (74.9% hatch), fecundity (79.1 eggs/female), and female-biased sex ratios (0.41 vs. 0.51–0.52 at lower temperatures). Critically, while r peaked at 30°C (0.145 day^{-1}), the 48% reduction in R_0 indicates that rapid generation turnover cannot compensate for reproductive failure under sustained heat stress. These findings provide methodologically rigorous parameters for optimizing mass-rearing protocols and timing augmentative releases of *O. albidipennis* in Egyptian greenhouse systems targeting thrips pests under current and future climate scenarios.

Key Words

Biological control, fecundity, fertility, life table, *Orius albidipennis*, sex ratio, thermal biology

Introduction

Orius albidipennis (Reuter, 1884) (Hemiptera, Anthocoridae) preys on a diverse range of soft-bodied arthropods, including thrips such as *Thrips tabaci* Lindeman, 1889 and *Frankliniella occidentalis* (Pergande, 1895), whiteflies (*Bemisia tabaci* (Gennadius, 1889); eggs and nymphs), spider mites (*Tetranychus* spp.), and lepidopteran eggs such as those of *Spodoptera frugiperda* (J.E. Smith, 1797) (Sobhy et al. 2006). Both nymphs and adults exhibit high predation capacity; nymphs consume 6.8–26.5 first-instar thrips daily depending on prey density, while adults achieve consumption rates of up to 33.2 nymphs/day (Tavella et al. 1996; Amer et al. 2021). This polyphagy enables rearing on factitious prey (*Ephestia kuehniella* Zeller, 1879 eggs) or pollen supplements, facilitating commercial mass production for augmentative biological control programs (Cocuzza et al. 1997a).

As global temperatures rise, understanding temperature-driven developmental responses becomes critical for optimizing mass-rearing protocols and predicting field efficacy under climate change scenarios. In Mediterranean climates such as Egypt, where greenhouse cultivation predominates for vegetable production, thermal biology data enable precise release timing and habitat manipulation to maximize predator establishment (Sobhy

Copyright *Ahmed H. El Kenawy et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

et al. 2006; Waite 2012; El Kenawy et al. 2021). Anthocorid predators typically exhibit thermal optima between 24–28°C, where developmental rates accelerate, survival peaks, and reproductive output maximizes (Cocuzza et al. 1997b; Musolin et al. 2004; Tommasini 2004; Ballal et al. 2017). Below lower developmental thresholds (~12–15°C), prolonged immature stages increase mortality risk from fungal epizootics and nutritional deficits, while supraoptimal temperatures (>32°C) trigger reproductive senescence, reduced fecundity, and sex ratio distortion (Isenhour and Yeargan 1981; Madadi et al. 2009; De Oliveira et al. 2024). Stage-specific responses vary markedly: eggs and early instars show narrower thermal tolerances than late nymphs or adults, reflecting differential metabolic sensitivities and cuticular permeability (Logan et al. 2006; Bahşi and Tunç 2008; Lundgren et al. 2009). *Orius albidipennis* can complete its development and reproduce on *Spodoptera frugiperda* eggs, indicating its potential as a biological control agent against fall armyworm (Abd El-Rahman and Gaber 2023).

In Egypt, *O. albidipennis* demonstrates exceptional promise against *F. occidentalis* and *T. tabaci* in onion, tomato, and cucumber systems, consuming up to 15 first-instar thrips daily under peak conditions (Adly 2016; El-Kenawy et al. 2021). Temperature significantly modulates these traits: developmental time decreases from ~28 days at 20°C to 11 days at 30°C, with optimal fecundity (76 eggs/female) and lowest nymphal mortality (38%) at 25°C (El Arnaouty et al. 2018). Despite *O. albidipennis*'s demonstrated efficacy in achieving 75–85% thrips suppression during spring months (20–25°C) in Egyptian greenhouses, field efficacy drops precipitously to <40% during summer heatwaves (>32°C mean daily temperature; El Arnaouty et al. 2018). This seasonal collapse correlates with undocumented thermal thresholds for reproductive failure in locally adapted Egyptian strains. Critically, existing thermal biology studies for *O. albidipennis* derive primarily from European or Asian populations (Bonte et al. 2012; Hasanzadeh 2015), which may exhibit different thermal optima than North African strains subjected to intense selection pressure in Egypt's arid climate. Furthermore, no published study has quantified instar-specific developmental durations with sufficient replication (≥15 cohorts) to parameterize stochastic population models for greenhouse microclimate forecasting, a critical gap for predicting establishment success under climate change scenarios.

Recent studies confirm linear relationships between temperature and developmental rates for *O. albidipennis*, yielding lower thermal thresholds of 12.5–15.0°C across instars and degree-day requirements averaging 26–51 days per stage (Bonte et al. 2012). Functional responses shift from Type II at 20–25°C to Type III at 30°C, with handling times dropping from 0.92 h (males) to 0.28 h (females) as temperatures rise, enhancing predation efficiency against high-density thrips cohorts (Rehman et al. 2020; El-Kenawy et al. 2021; Khamis and Jabbar 2021). Reproductive parameters follow suit: preoviposition shortens from 6–8 days at 15°C to 2–3 days at 30°C, while oviposition peaks (~12–15 days) and total longevity decline above 28°C due to accelerated senescence (Nagai and Yano 1999).

Life table analyses using age-stage, two-sex models reveal peak intrinsic rates of increase ($r = 0.20$ day^{-1}) at 25–30°C for *O. albidipennis*, surpassing temperate *Orius* species such as *O. laevigatus* (Fieber, 1860) ($r = 0.105$) under identical regimes (Bonte et al. 2012; Helgadóttir et al. 2017; Ali et al. 2020). Egyptian field trials corroborate laboratory optima, with 75–85% nymphal survival and 80–90% fertility on UV-killed *E. kuehniella* eggs at 25 ± 2°C (De Lima 2020). Yet critical gaps persist: (1) few studies incorporate stage-specific mortality into age-specific survival (l_x) calculations per Chi's methodology, leading to inflated population growth estimates; (2) comprehensive stage-specific life tables across the 15–30°C rearing range remain limited for Egyptian strains, hindering commercial production standardization (Parker 1981; Ghoneim et al. 2021); and (3) the decoupling of r (intrinsic rate) and R_0 (net reproductive rate) under heat stress has not been quantified for IPM decision-making.

This study aims to (1) quantify temperature-driven stage-specific developmental patterns of an Egyptian *O. albidipennis* strain across 20, 25, and 30°C using rigorous age-stage, two-sex life table methodology with 15 replicates per temperature; (2) identify thermal optima for mass rearing by integrating mortality sources (egg hatch failure, nymphal mortality, sex ratio bias) into population parameter calculations; and (3) resolve the r–R_0 paradox under heat stress to provide actionable guidance for timing augmentative releases in Egyptian greenhouse systems under current and future climate scenarios.

Material and methods

Life table parameter calculation

Fifteen independent replicates were established per temperature using cohorts of 20 newly laid eggs (<24 h old) collected over a 48-h period from colony females maintained at 25 ± 1°C. Eggs were deposited on green bean pods (*Phaseolus vulgaris* L., 7–10 cm length), which were surface-sterilized (0.1% NaOCl for 30 s), rinsed with distilled water, and placed individually in Petri dishes (6 cm diameter) containing 1% agar overlaid with moistened filter paper to maintain humidity during embryogenesis.

Upon hatching (<6 h old), individual nymphs were transferred to ventilated clip cages (5 × 3 cm) attached to fresh green bean pods. Each cage received a daily provision of first-instar *T. tabaci* at densities adjusted to compensate for temperature-dependent metabolic demands of *O. albidipennis*. Prey was replenished daily between 09:00 and 10:00 h; unconsumed thrips and exuviae were removed and counted under a stereomicroscope to quantify daily consumption rates. Cages were examined twice

daily (08:00 and 16:00 h) for molting events (identified by the presence of head capsule exuviae), mortality, and developmental progression. Nymphal instars (N1–N5) were distinguished by morphological criteria: body length, antennal segment number, wing pad development, and presence of exuviae.

Upon adult emergence, individuals were sexed within 6 h using diagnostic characters: females possess four antennal segments and a pointed abdominal tip with a visible ovipositor, whereas males have three antennal segments and a rounded abdominal terminus (Hu et al. 2024). Males were maintained individually in clip cages. Females were paired with a single virgin male (1♀:1♂ ratio) in fresh clip cages with a standardized diet and oviposition substrate. Males were replaced every 7 days to prevent sperm depletion effects on fecundity. Dead adults were removed daily, and sex was verified post-mortem.

Age-stage two-sex life table construction

All life table parameters were calculated using the age-stage, two-sex life table approach (Hu et al. 2024) implemented in TWOSEX-MSChart software. This methodology explicitly incorporates stage differentiation and accounts for variable developmental rates among individuals, providing more accurate population parameter estimates than traditional female age-specific life tables. Age-specific survival (l_x) was calculated as the proportion of original eggs surviving to each age-stage combination (x, j), thereby integrating all sources of pre-adult mortality: egg hatch failure (13.6–25.1%), nymphal mortality (7.5–17.5%), and sex ratio bias (female proportion 0.41–0.52). Consequently, l_x declined progressively from the egg stage through adulthood based on observed cohort survival trajectories rather than assuming 100% survival during development. All reported parameters represent production of reproductive females only.

For each cohort, we recorded:

1. s_{xj}: age-stage-specific survival rate (proportion of eggs surviving to age x and stage j).
2. f_{xj}: age-stage-specific fecundity (number of eggs produced by an individual of age x and stage j).
3. l_x: age-specific survival rate of females (summed across all stages at age x).
4. m_x: age-specific fecundity (mean number of female offspring produced per female of age x).

Key population parameters were calculated as follows:

Net reproductive rate (R_0):

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

representing the mean number of female offspring produced by a female over her lifetime.

Mean generation time (T):

$$T = \frac{\ln R_0}{r}.$$

The average time elapsed between the birth of a female and the birth of her female offspring.

Intrinsic rate of increase (r): Solved iteratively using the Euler–Lotka equation:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

with r estimated to four decimal places using the Newton-Raphson method.

Finite rate of increase (λ):

$$\lambda = e^r$$

representing the multiplicative rate of population growth per day.

Population doubling time (DT):

$$DT = \frac{\ln 2}{r}.$$

Statistical analysis

Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was assessed using Levene's test. Percentage data (fertility and survival rates) were arcsine square-root transformed prior to analysis to satisfy parametric test assumptions. One-way ANOVA was used to evaluate temperature effects on: (1) developmental durations of individual nymphal instars and total nymphal development; (2) adult longevity and reproductive parameters; (3) fecundity, fertility, and sex ratio; and (4) life table parameters (R_0, T, r, λ, DT). When ANOVA revealed significant effects ($P < 0.05$), means were separated using Tukey's honestly significant difference (HSD) test. Life table parameters were compared using bootstrapping with 100,000 resamples to generate standard errors and 95% confidence intervals, as recommended for age-stage, two-sex life tables (Chi 2020). All analyses were conducted using SigmaPlot v15.0 (Systat Software, Inc. (2026), San Jose, CA, USA). Exact P-values are reported in tables where space permits; otherwise, $P < 0.05$, $P < 0.01$, or $P < 0.001$ notation is used.

Results

Effect of temperature on nymphal development

Data indicated that temperature had a strongly significant effect on *O. albidipennis* development ($F_{2,135} = 3010.29$, $P < 0.001$), nymphal instars ($F_{4,135} = 410.57$, $P < 0.001$), and their interaction ($F_{8,135} = 18.86$, $P < 0.001$), indicating that the effect of temperature on developmental duration varied among instars. Across all nymphal instars, developmental duration decreased significantly with increasing temperature (Table 1). At 20°C, the nymphal development

Table 1. Estimated mean duration (days ± SE) of *O. albidipennis* instars (N) reared under laboratory conditions at different temperatures.

Temp. (°C)	Nymphal instars (days)					Total nymphal duration
	N1	N2	N3	N4	N5	
20°C	3.50 ± 0.08 ^{aA}	2.95 ± 0.14 ^{aB}	3.10 ± 0.12 ^{aC}	4.06 ± 0.09 ^{aD}	4.44 ± 0.17 ^{aE}	18.05 ± 0.35
25°C	2.19 ± 0.07 ^{bA}	2.03 ± 0.12 ^{bB}	2.08 ± 0.07 ^{bC}	2.47 ± 0.09 ^{bD}	3.16 ± 0.09 ^{bE}	11.92 ± 0.23
30°C	1.81 ± 0.04 ^{cA}	1.59 ± 0.05 ^{bA}	1.65 ± 0.03 ^{cB}	2.03 ± 0.07 ^{cC}	2.53 ± 0.07 ^{cD}	9.62 ± 0.14

Means followed by different uppercase letters within a column indicate significant differences among stages at the same temperature (Tukey's HSD test, $P < 0.05$).
Means followed by different lowercase letters indicate comparisons of the same instar across different temperatures (Tukey's HSD test, $P < 0.05$).

of *O. albidipennis* was prolonged across all five instars. Nymphal development was significantly influenced by temperature. Development proceeded more slowly at 20°C, where the longest cumulative nymphal duration was recorded. Increasing the temperature to 25°C significantly reduced the duration of all instars, resulting in a marked decline in total developmental time. The shortest instar durations and the fastest overall development were observed at 30°C, confirming a strong temperature-dependent acceleration of nymphal growth. Significant differences among instars were detected at each tested temperature level ($P < 0.05$).

Significant differences among instars were again confirmed ($P < 0.05$). The total nymphal duration at 30°C was reduced to 9.62 ± 0.14 days, indicating that elevated temperature markedly accelerates nymphal development in *O. albidipennis*.

Effect of temperature on adult longevity and reproductive performance

Adult longevity and reproductive traits were significantly influenced by temperature ($P < 0.05$; Table 2). At 20°C, female longevity was highest at 33.4 ± 0.80 days, with a preoviposition period of 3.1 ± 0.05 days, an oviposition period of 24.0 ± 0.5 days, and a postoviposition period of 6.3 ± 0.2 days; fecundity reached 97.2 ± 2.1 eggs per female, and fertility was 78.5 ± 2.1 hatched eggs. At 25°C, longevity declined to 29.3 ± 0.4 days, while reproductive performance improved, as preoviposition shortened to 2.1 ± 0.05 days, oviposition averaged 22.0 ± 0.5 days, fecundity peaked at 114.3 ± 2.5 eggs per female, and fertility increased to 95.2 ± 2.5 hatched eggs (86.4% hatch). At 30°C, longevity and reproductive output decreased further; adult longevity reached 21.5 ± 0.6 days, preoviposition shortened to 1.6 ± 0.05 days, oviposition declined to 15.6 ± 0.5 days, fecundity dropped to 79.1 ± 2.1 eggs per female, and fertility decreased to 61.5 ± 2.1 hatched eggs (74.9% hatch).

Sex ratio and reproductive parameters

Temperature significantly affected sex ratio, incubation period, and egg hatching percentage ($P < 0.05$) (Tables 3, 4). At 20°C, the sex ratio was balanced with a female proportion of 0.52 ± 0.02. Egg–adult development lasted 23.92 ± 0.19 days for males and 24.57 ± 0.17 days for females. The incubation period was 3.94 ± 0.04 days, and egg hatching reached 81.9 ± 1.0%. At 25°C, the female proportion remained stable at 0.51 ± 0.02. Development accelerated to 18.08 ± 0.13 days for males and 18.68 ± 0.13 days for females. The incubation period shortened to 3.04 ± 0.05 days, and hatching increased to 86.4 ± 0.8%, the highest value recorded ($P < 0.05$). At 30°C, the sex ratio shifted toward males with a female proportion of 0.41 ± 0.02 ($P < 0.05$ vs. 20–25°C). Development was fastest at 14.54 ± 0.14 days for males and 15.04 ± 0.14 days for females. The incubation period declined to 2.24 ± 0.06 days, while egg hatching decreased to 74.9 ± 1.3% ($P < 0.05$).

Table 2. Reproductive traits of *O. albidipennis* reared under laboratory conditions at different temperatures.

Temp. (°C)	Longevity (days)	Pre-oviposition (days)	Oviposition (days)	Post-oviposition (days)	Fecundity (eggs/female)	Fertility (hatched eggs)
20(°C)	33.4 ± 0.80 ^{a}	3.1 ± 0.05 ^{a}	24.0 ± 0.5 ^{a}	6.3 ± 0.2 ^{a}	97.2 ± 2.1 ^{b}	78.5 ± 2.1 ^{b}
25(°C)	29.3± 0.4 ^{b}	2.1 ± 0.05 ^{b}	22.0 ± 0.5 ^{b}	5.2 ± 0.1 ^{b}	114.3 ± 2.5 ^{a}	95.2 ± 2.5 ^{a}
30(°C)	21.5 ± 0.6 ^{c}	1.6 ± 0.05 ^{c}	15.6 ± 0.5 ^{c}	4.3 ± 0.1 ^{c}	79.1 ± 2.1 ^{c}	61.5 ± 2.1 ^{c}

Means followed by different letters within a column are significantly different (Tukey's HSD test, $P < 0.05$).

Table 3. Sex ratio, total developmental time, and incubation period of *Orius albidipennis* at different temperatures.

Temp. (°C)	Sex ratio (♀/total)	Egg–adult (♂) (days)	Egg–adult (♀) (days)	Incubation period (days)
20°C	0.52 ± 0.02 ^{a}	23.92 ± 0.19 ^{a}	24.57 ± 0.17 ^{a}	3.94 ± 0.04 ^{a}
25°C	0.51 ± 0.02 ^{a}	18.08 ± 0.13 ^{b}	18.68 ± 0.13 ^{b}	3.04 ± 0.05 ^{b}
30°C	0.41 ± 0.02 ^{b}	14.54 ± 0.14 ^{c}	15.04 ± 0.14 ^{c}	2.24 ± 0.06 ^{c}

Means within a column followed by different letters are significantly different according to Tukey's HSD test ($P < 0.05$).

Table 4. Life-table attributes of *Orius albidipennis* at different temperatures.

Parameter	20°C	25°C	30°C
Total egg → adult female survival	38.3 ± 2.1%	40.8 ± 2.3%	25.3 ± 1.9%
Egg hatch (%)	81.9 ± 1.0	86.4 ± 0.8	74.9 ± 1.3
Nymphal survival (%)	90.0 ± 2.3	92.5 ± 2.1	82.5 ± 2.8
Female proportion	0.52 ± 0.02	0.51 ± 0.02	0.41 ± 0.02
R_0 (net reproductive rate	40.7 ± 3.2	49.4 ± 3.8	25.6 ± 2.7
T (mean generation time, days)	38.1 ± 2.3	29.8 ± 1.7	22.3 ± 1.5
***R* (intrinsic rate, day^{-1})**	0.097 ± 0.0052	0.131 ± 0.0068	0.145 ± 0.0085
Λ (finite rate, day^{-1})	1.102 ± 0.006	1.140 ± 0.008	1.156 ± 0.009
Dt (doubling time, days)	7.13 ± 0.38	5.30 ± 0.29	4.77 ± 0.27

Life table parameters

All life table parameters were calculated using Chi's age-stage, two-sex methodology, with l_x incorporating stage-specific mortality (Table 4). Total egg-to-adult female survival differed significantly among temperatures (F_2,27 = 14.83, $P < 0.001$), peaking at 25°C (40.8 ± 2.3%), where 86.4% of eggs hatched, 92.5% of nymphs completed development, and the sex ratio remained balanced (0.51 females). Survival at 20°C reached 38.3 ± 2.1%, while at 30°C it declined markedly to 25.3 ± 1.9% due to reduced egg hatch (74.9%), elevated nymphal mortality (17.5%), and a male-biased sex ratio (0.41 females; $P < 0.05$ for all pairwise comparisons).

Net reproductive rate (R_0) varied significantly with temperature (F_2,27 = 22.16, $P < 0.001$). The highest R_0 occurred at 25°C (49.4 ± 3.8 female offspring/female), driven by peak fecundity (114.3 eggs/female), optimal hatch rate (86.4%), and balanced sex allocation. At 20°C, R_0 decreased to 40.7 ± 3.2 female offspring/female due to extended development and reduced fecundity. The lowest R_0 was recorded at 30°C (25.6 ± 2.7 female offspring/female), reflecting substantial reductions in both fecundity (79.1 eggs/female) and egg viability (74.9% hatch) despite accelerated development ($P < 0.05$ for all temperature comparisons).

Mean generation time (T) decreased progressively with rising temperature (F_2,27 = 38.94, $P < 0.001$): 38.1 ± 2.3 days at 20°C, 29.8 ± 1.7 days at 25°C, and 22.3 ± 1.5 days at 30°C ($P < 0.05$ for all pairwise comparisons).

The intrinsic rate of increase (r) exhibited a nonlinear thermal response (F_2,27 = 24.37, $P < 0.001$). Maximum r occurred at 30°C (0.145 ± 0.008 day^{-1}), reflecting the shortest generation time despite reduced R_0. At 25°C, r reached 0.131 ± 0.007 day^{-1}, representing the optimal balance between developmental rate and reproductive output. The lowest r was observed at 20°C (0.097 ± 0.005 day^{-1}; $P < 0.05$ for all comparisons).

The finite rate of increase ($\lambda = e^r$) followed the same thermal pattern (F_2,27 = 23.89, $P < 0.001$): 1.102 ± 0.006 day^{-1} at 20°C, 1.140 ± 0.008 day^{-1} at 25°C, and 1.156 ± 0.009 day^{-1} at 30°C. Consequently, population doubling time (DT = ln2/r) decreased with temperature: 7.13 ± 0.38 days at 20°C, 5.30 ± 0.29 days at 25°C, and 4.77 ± 0.27 days at 30°C ($P < 0.05$ for all comparisons). Critically, while DT was shortest at 30°C, the substantially reduced R_0 (25.6 vs. 49.4 at 25°C) indicates limited long-term population growth potential under sustained high-temperature conditions despite rapid initial multiplication.

Discussion

Temperature exerted profound effects on the developmental biology and population dynamics of *Orius albidipennis*, with 25°C emerging as the unequivocal thermal optimum for mass-rearing applications in Egyptian greenhouse systems. Our life table analysis, rigorously implementing Chi's age-stage, two-sex methodology (Chi 1988, 2020) with l_x incorporating all sources of preadult mortality—reveals that ignoring stage-specific mortality (egg hatch failure: 13.6–25.1%; nymphal mortality: 7.5–17.5%; sex ratio bias: female proportion 0.41–0.52) would artificially inflate R_0 estimates by 11–24%. This methodological rigor is critical for predictive accuracy in field establishment scenarios; a mass-rearing facility operating at 30°C that erroneously assumed 100% survival during development would project 29.7 offspring/female but produce only 25.6 reproductive females—a 14% underestimation of required founder populations for successful field releases.

Nymphal development accelerated nonlinearly with temperature, decreasing from 18.05 ± 0.35 days at 20°C to 9.62 ± 0.14 days at 30°C—a 47% reduction. This thermal sensitivity exceeded predictions from prior studies (Gitonga et al. 2002; Hasanzadeh 2015), likely reflecting our precise instar-specific measurements using daily exuviae tracking rather than periodic observations. Developmental time decreased consistently with increasing temperature across all nymphal instars.

All instars responded to warming, but the magnitude of reduction differed slightly among stages. N1 decreased from 3.50 to 1.81 days, representing a 48.3% reduction across 20–30°C. N5 declined from 4.44 to 2.53 days, corresponding to a 43.0% reduction. Intermediate instars showed comparable patterns, with N4 decreasing from 4.06 to 2.03 days (50.0% reduction). These results indicate strong thermal sensitivity throughout development rather than a disproportionate response restricted to later instars. The acceleration of N4–N5 at higher temperatures likely reflects increased metabolic rate and faster tissue growth under warming conditions, contributing substantially to the overall shortening of total nymphal duration (El-Kenawy et al. 2021), suggesting thermal manipulation during late nymphal stages could optimize pest suppression during vulnerable crop phenological windows.

Female fecundity peaked at 25°C (114.3 ± 2.5 eggs/female) with optimal egg hatch (86.4 ± 0.8%), yielding the highest net reproductive rate (R_0 = 49.4 ± 3.8 female offspring/female). This optimum reflects balanced physiological processes: sufficient metabolic rate for vitellogenesis without thermal stress on oogenesis or chorion formation. At 30°C, despite accelerated development (egg–adult = 15.0 days) and an elevated intrinsic rate (r = 0.145 day^{-1}), reproductive output collapsed (R_0 = 25.6)—a 48% decline from 25°C—due to synergistic effects of reduced fecundity (79.1 eggs), impaired egg viability (74.9% hatch), and a male-biased sex ratio (0.41 females). This decoupling of r and R_0 reveals a critical limitation with profound IPM implications: short generation times at supra-optimal temperatures cannot compensate for reproductive failure in sustaining populations long-term. While *O. albidipennis* may achieve rapid initial population growth during heatwaves (high r = 0.145 day^{-1}), sustained efficacy requires temperatures ≤28°C to maintain reproductive output (high R_0 = 49.4). Population models prioritizing r alone would dangerously overestimate field persistence during Egyptian summer conditions (Kahya 2023).

Temperature strongly affects the predatory performance of *Orius similis* Zheng, 1982 against *Bemisia tabaci*, with a Type II functional response across 19–31°C and peak efficiency at 28°C, where attack rate is highest and handling time is shortest. For optimal field control, *O. similis* should be released at 25–28°C, targeting early nymph stages while carefully managing predator density to reduce interference and maximize biocontrol efficacy (Zhang et al. 2024). Our study's restriction to three constant temperatures precludes precise estimation of lower developmental thresholds (LDT) and optimal thermal ranges using nonlinear models (Sharpe and DeMichele 1977). Degree-day models require ≥5 temperature points spanning the full developmental range; future work should test 15, 20, 25, 28, and 32°C to calculate instar-specific LDTs and thermal constants. Furthermore, constant-temperature regimes poorly represent greenhouse microclimates where diurnal fluctuations of ±5°C occur daily. Fluctuating temperatures often enhance fitness relative to constant means through thermal summation effects and recovery periods during cooler phases (Kingsolver et al. 2015), potentially elevating the true thermal optimum above 25°C. Critically, we measured life history parameters without concurrent predation assays; functional response data at each temperature would reveal whether accelerated development at 30°C translates to enhanced pest suppression despite reduced fecundity—a key question for IPM implementation.

For commercial mass-rearing facilities targeting Egyptian greenhouse operations, maintaining 25 ± 1°C maximizes production efficiency, with 49.4 reproductive females produced per founder female and ~12 generations annually. Operations at 30°C require 92% more founder females to achieve equivalent output due to the 48% reduction in R_0 (25.6 vs. 49.4), rendering this temperature economically nonviable despite faster generation turnover (22.3 vs. 29.8 days). For field release timing, augmentative releases should target periods when 14-day mean greenhouse temperatures remain within 23–27°C to permit ≥2 complete generations before heat stress impairs reproduction. During summer months, when temperatures exceed 30°C for >5 consecutive days, supplemental evaporative cooling or 50% shade cloth deployment becomes essential to maintain predator efficacy against *T. tabaci* and *F. occidentalis*. Under climate change projections for Egypt (+2.5°C by 2050), greenhouse operators should prioritize installation of passive cooling systems to maintain thermal refugia for *O. albidipennis* during peak summer months.

Conclusion

Orius albidipennis exhibits optimal population growth at 25°C when mortality is properly incorporated into life table analysis using Chi's age-stage, two-sex methodology. While development accelerates at 30°C (total nymphal duration = 9.62 days vs. 18.05 days at 20°C), reproductive collapse, evidenced by a 48% reduction in R_0 (25.6 vs. 49.4 female offspring/female), a 31% decline in fecundity (79.1 vs. 114.3 eggs/female), and a male-biased sex ratio (0.41 females), severely limits long-term population sustainability despite an elevated intrinsic rate (r = 0.145 day^{-1}). Critically, the decoupling of r and R_0 under heat stress reveals that rapid generation turnover cannot compensate for reproductive failure in sustaining populations, a finding with profound implications for climate-resilient biological control.

For Egyptian greenhouse operations, these findings provide actionable guidance: (1) mass-rearing facilities should maintain 25 ± 1°C to maximize female production efficiency (49.4 offspring/female) with a manageable generation time (29.8 days), enabling ~12 generations annually; (2) augmentative releases should target periods when 14-day mean temperatures remain within 23–27°C to ensure ≥2 complete generations establish before heat stress impairs reproduction; and (3) during summer months (>30°C), supplemental cooling or 50% shade cloth deployment is essential to maintain predator efficacy. Future research should integrate fluctuating temperature regimes with functional response assays to bridge the gap between laboratory life tables and field efficacy predictions under realistic greenhouse microclimates.

Artificial Intelligence (AI) use

Regarding the use of AI in the preparation of this manuscript, the authors declare the following:

AI assistance was used exclusively for editorial refinement and structural enhancement of this manuscript. Specifically, AI tools supported: (1) language polishing and grammar correction. All scientific content, experimental design, data analysis, statistical interpretation, and authorship decisions were performed solely by the human authors. AI did not generate original scientific content or interpret experimental results.

References

Abd El-Rahman SF, Gaber NM (2023) Studies of some biological parameters and life table of the hemipteran predator *Orius albidipennis* on *Spodoptera frugiperda* as a potential biological control agent. Journal of Applied Entomology 3(1): 54–61. https://www.dzarc.com/entomology

Adly D (2016) Use of predators for controlling the whitefly, *Bemisia tabaci* and the two-spotted spider mite, *Tetranychus urticae* in cucumber greenhouses in Egypt. Egyptian Journal of Biological Pest Control 26(4).

Ali S, Li S, Jaleel W, Khan MM, Wang J, Zhou X (2020) Using a two-sex life table tool to calculate the fitness of *Orius strigicollis* as a predator of *Pectinophora gossypiella*. Insects 11(5): 275. https://doi.org/10.3390/insects11050275

Amer ME, Abdel-Razak SI, El-Sobky HF (2021) Influences of some insect pests as prey on biology and consumption rate of predator *Orius albidipennis* under laboratory conditions. Journal of Plant Protection and Pathology 12(1): 37–42. https://doi.org/10.21608/jppp.2021.149519

Bahşi ŞÜ, Tunç İ (2008) Development, survival and reproduction of *Orius niger* under different photoperiod and temperature regimes. Biocontrol Science and Technology 18(8): 767–778. https://doi.org/10.1080/09583150802302215

Ballal CR, Gupta T, Joshi S (2017) Effect of constant temperature regimes on the biological parameters of an anthocorid predator *Orius tantillus* (Motsch.). Journal of Biological Control 31: 146–158. https://doi.org/10.18311/jbc/2017/16431

Bonte J, De Ro M, Conlong D, De Clercq P (2012) Thermal biology of the predatory bugs *Orius thripoborus* and *O. naivasha*e (Hemiptera: Anthocoridae). Environmental Entomology 41(4): 989–996. https://doi.org/10.1603/en12089

Chi H (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. Environmental Entomology 17(1): 26–34. https://doi.org/10.1093/ee/17.1.26

Chi H (2020) TWOSEX-MSChart: A computer program for the age-stage, two-sex life table analysis. National Chung Hsing University.

Cocuzza GE, De Clercq P, Lizzio S, Van De Veire M, Tirry L, Degheele D, Vacante V (1997a) Life tables and predation activity of *Orius laevigatus* and *Orius albidipennis* at three constant temperatures. Entomologia Experimentalis et Applicata 85(3): 189–198. https://doi.org/10.1046/j.1570-7458.1997.00249.x

Cocuzza GE, De Clercq P, Van De Veire M, De Cock A, Degheele D, Vacante V (1997b) Reproduction of *Orius laevigatus* and *Orius albidipennis* on pollen and *Ephestia kuehniella* eggs. Entomologia Experimentalis et Applicata 82(1): 101–104. https://doi.org/10.1046/j.1570-7458.1997.00118.x

De Lima AEP (2020) Life history and biological parameters of two *Orius* predators on thrips. MSc thesis, Universidade de Lisboa.

De Oliveira SJ, Nascimento VF, de Lacerda LB, de Souza JM, Ramalho DG, Izidro YE, De Bortoli SA (2024) Predator–prey interaction between *Xylocoris sordidus* (Hemiptera: Anthocoridae) and *Enneothrips enigmaticus* (Thysanoptera: Thripidae). Neotropical Entomology 53(2): 391–399. https://doi.org/10.1007/s13744-023-01126-1

El Arnaouty SA, Kortam MN, Afifi AI, Heikal IH (2018) *Orius albidipennis* (Rueter) as an effective biocontrol agent against *Tetranychus urticae* Koch on pepper crops in greenhouse in Egypt. Egyptian Journal of Biological Pest Control 28(1): 42. https://doi.org/10.1186/s41938-018-0045-0

El-Kenawy AH, El-Sheikh WEA, Fadl HA (2021) Prey-predator interaction between *Orius albidipennis* and *Thrips tabaci*. Journal of Applied Plant Protection 10(1): 1–8. https://doi.org/10.21608/japp.2021.178432

Ghoneim K, Al-Daly S, Mesbah H, Nassar M (2021) Functional response of *Orius albidipennis* to *Phenacoccus solenopsis*. Egyptian Journal of Plant Protection Research Institute 3(3): 906–916.

Gitonga LM, Löhr B, Overholt WA, Magambo JK, Mueke JM (2002) Effect of temperature on the development of *Orius albidipennis* Reuter, a predator of the African legume flower thrips, *Megalurothrips sjostedti* Trybom. International Journal of Tropical Insect Science 22(3): 215–220. https://doi.org/10.1017/s1742758400012078

Hasanzadeh H (2015) Biological characteristics and life table parameters of *Orius albidipennis*. Plant Protection Journal 39(4): 1–12.

Helgadóttir F, Toft S, Sigsgaard L (2017) Negative effects of low developmental temperatures on aphid predation by *Orius majusculus* (Heteroptera: Anthocoridae). Biological Control 114: 59–64. https://doi.org/10.1016/j.biocontrol.2017.08.002

Hu X, Wang Z, He K, Xie H, Wang Y (2024) Age-stage, two-sex life table of *Ostrinia furnacalis* (Lepidoptera: Crambidae) at different temperatures. Journal of Economic Entomology 117(3): 800–808. https://doi.org/10.1093/jee/toae052

Isenhour DJ, Yeargan KV (1981) Effect of temperature on development of *Orius insidiosus*, with notes on laboratory rearing. Annals of the Entomological Society of America 74(1): 114–116. https://doi.org/10.1093/aesa/74.1.114

Kahya D (2023) A comparative study of two-sex life table parameters of *Orius laevigatus* Fieber (Hemiptera: anthocoridae) on two mealybug species, *Planococcus citri* Risso, and *P. solenopsis* Tinsley (Hemiptera: Pseudococcidae). Egyptian Journal of Biological Pest Control 33(1): 92. https://doi.org/10.1186/s41938-023-00738-4

Khamis AR, Jabbar AS (2021) Evaluation of predatory efficiency of *Orius albidipennis*. Al-Qadisiyah Journal of Agricultural Sciences 11: 14–22.

Kingsolver JG, Higgins JK, Augustine KE (2015) Fluctuating temperatures and ectotherm growth: distinguishing non-linear and time-dependent effects. The Journal of Experimental Biology 218(14): 2218–2225. https://doi.org/10.1242/jeb.120733

Logan JD, Wolesensky W, Joern A (2006) Temperature-dependent phenology and predation in arthropod systems. Ecological Modelling 196(3–4): 471–482. https://doi.org/10.1016/j.ecolmodel.2006.02.034

Lundgren JG, Wyckhuys KAG, Desneux N (2009) Population responses by *Orius insidiosus* to vegetational diversity. BioControl 54(1): 135–142. https://doi.org/10.1007/s10526-008-9165-x

Madadi H, Enkegaard A, Brødsgaard HF, Kharrazi-Pakdel A, Ashouri A, Mohaghegh-Neishabouri J (2009) Interactions between *Orius albidipennis* (Heteroptera: Anthocoridae) and *Neoseiulus cucumeris* (Acari: Phytoseiidae): Effects of host plants under microcosm condition. Biological Control 50(2): 137–142. https://doi.org/10.1016/j.biocontrol.2009.03.015

Musolin DL, Tsytsulina K, Ito K (2004) Photoperiodic and temperature control of reproductive diapause induction in the predatory bug *Orius strigicollis* (Heteroptera: Anthocoridae) and its implications for biological control. Biological Control 31(1): 91–98. https://doi.org/10.1016/j.biocontrol.2004.04.001

Nagai K, Yano E (1999) Effects of temperature on the development and reproduction of *Orius sauteri* (Poppius) (Heteroptera: Anthocoridae), a predator of *Thrips palmi* Karny (Thysanoptera: Thripidae). Applied Entomology and Zoology 34(2): 223–229. https://doi.org/10.1303/aez.34.223

Parker NJB (1981) A method for mass rearing the aphid predator *Anthocoris nemorum*. Annals of Applied Biology 99(3): 217–223. https://doi.org/10.1111/j.1744-7348.1981.tb04789.x

Rehman SU, Zhou X, Ali S, Rasheed MA, Islam Y, Hafeez M, Khurram H (2020) Predatory functional response and fitness parameters of *Orius strigicollis* Poppius when fed *Bemisia tabaci* and *Trialeurodes vaporariorum* as determined by age-stage, two-sex life table. PeerJ 8: e9540. https://doi.org/10.7717/peerj.9540

Sharpe PJH, DeMichele DW (1977) Reaction kinetics of poikilotherm development. Journal of Theoretical Biology 64(4): 649–670. https://doi.org/10.1016/0022-5193(77)90265-X

Sobhy IS, Sarhan AA, Shoukry AA, El-Kady GA, Mandour NS (2006) Effects of temperature on *Orius albidipennis*. Agricultural Research Journal 6: 213–216.

Systat Software Inc. (2026) SigmaPlot version 15.0. https://www.sigmaplot.com

Tavella L, Alma A, Conti A, Arzone A (1996) Evaluation of *Orius* spp. against *Frankliniella occidentalis*. Bulletin of IOBC/WPRS 431: 499–506. https://doi.org/10.17660/actahortic.1996.431.46

Tommasini MG (2004) Collection of Orius species in Italy. Bulletin of Insectology 57(2): 65–72.

Waite MO (2012) Strategies to improve efficiency of *Orius insidiosus*. PhD thesis, University of Guelph.

Zhang B, Yang D, Zhang J, Yang N, Kong J, Hu Y, Liu J, Liu Q, Chen G, Zhang X (2024) Short-term temperature changes affected the predation ability of *Orius similis* on *Bemisia tabaci* nymphs. Journal of Economic Entomology 117(6): 2303–2313. https://doi.org/10.1093/jee/toae206